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ABSTRACT

The Paleocene Tongue River Member of the Fort Union Formation contains trace-fossil associations indicative of marine influence in otherwise freshwater facies. The identified ichnogenera include: *Arenicolites*, *Diplocraterion*, *Monocraterion*, *Ophiomorpha*, *Rhizocorallium*, *Skolithos linearis*, *Teichichnus*, *Thalassinoides,* and one form of uncertain affinity. Two species of the marine diatom *Coscinodiscus* occur a few meters above the base of the member. The burrows occur in at least five discrete, thin, rippled, fine-grained sandstone beds within the lower 85 m of the member west of the Cedar Creek anticline (CCA) in the Signal Butte, Terry Badlands, and Pine Hills areas. Two discrete burrowed beds are found in the lower 10 m of the member east of the CCA in the little Missouri River area.

Abundant freshwater ostracodes include *Bisulcocypridea arvadensis*, *Candona*, and *Cypridopsis*. Freshwater bivalves include *Plesielliptio* and *Pachydon mactriformis*. We recognize four fossil assemblages that represent fluvio-lacustrine, proximal estuarine, central estuarine, and distal estuarine environments. Biostratal alternations between fresh- and brackish-water assemblages indicate that the Tongue River Member was deposited along a low-gradient coastal plain that was repeatedly inundated from the east by the Cannonball Sea.

The existence of marine-influenced beds in the Tongue River Member invalidates the basis for the Slope Formation.

KEY WORDS: bivalves, diatoms, estuarine environment, Fort Union Formation, Tongue River Member, Ostracoda, trace fossils, Paleocene, Williston Basin.

INTRODUCTION

The Tongue River Member of the Fort Union Formation (Fig. 1) traditionally has been considered an exclusively freshwater deposit (Belt et al., 1984, 1992; Flores, 1981; Flores et al., 1999). Marine trace fossils were not previously recorded from this deposit, although some of the same taxa were identified from the coeval Ekalaka Member in Montana (Belt et al., 2002) and from the underlying Three V Tongue (Fig. 2*B*) of the Cannonball Member in western North Dakota (van Alstine, 1974). Our new paleontological findings include assemblages of trace fossils and body fossils such as ostracodes, bivalves, and diatoms. These demonstrate high-frequency alternations between freshwater and marginal-marine deposits. The relationship between laterally extensive, marine burrowed beds and zones of coal accumulation suggests that marine incursions were far-reaching and short-lived.

Our earlier report (Belt et al., 2004) indicates the frequency and local correlation of the marine-influenced beds that are reported here in greater detail. Their regional correlation cannot be ascertained at present because of disparities in age between strata of the lower Tongue River Member on either side of the Cedar Creek anticline.

The discovery of these marine-influenced beds invalidates the use of Slope Formation, which was defined by Clayton et al. (1977) on the basis of marine or brackish beds that they believed were confined exclusively to strata older than the Tongue River Member. Slope Formation has been used widely in North Dakota (Clayton et al., 1980; Hartman, 1993b) but only rarely in Montana or South Dakota.

GEOLOGIC BACKGROUND

Fossil Localities

The fossils illustrated in this report are from four districts in eastern Montana and southwestern North Dakota (Fig. 1): Signal Butte (*SB*); Terry Badlands (*TB*); Pine Hills (*PH*); and the Little Missouri River (*LMR*). Appendix 1 lists the stratigraphic positions and geographic coordinates for the named units presented herein. The Ekalaka and Cave Hills study areas were previously described (Belt et al., 2002).

Stratigraphy

The Fort Union Formation has been subdivided into the various members shown in Figure 2. We do not use the North Dakota terminology of Clayton et al. (1977). In central North Dakota, the Tongue River Member overlies the main body of the marine Cannonball Member. In eastern Montana and southwestern North Dakota (Fig. 2), deltaic facies of the Ludlow Member intertongue with the Three V and Boyce Tongues of the Cannonball Member (Belt et al., 1984; Hartman, 1993a, 1993b; Lund et al., 2002), and the Tongue River Member forms the top of the Fort Union Formation. To the west, in eastern Montana, fluvio-lacustrine strata dominate west of the Cedar Creek anticline (*CCA*; Figs. 1 and 2*A*). There, the thick, regionally extensive C-coal zone defines the contact between the Tullock and Lebo Members; strata of the Lebo Member underlie the Tongue River Member (Fig. 2*A*).

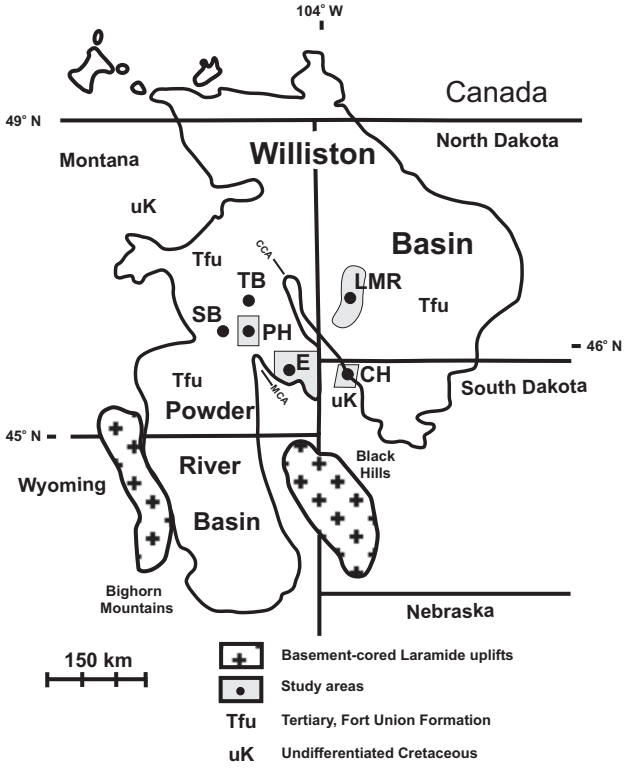


Figure 1. Map of Williston and Powder River Basins. Heavy line approximates boundary between the Hell Creek–Lance Formations (uK, Upper Cretaceous) and Fort Union Formation (Tfu, Paleocene). Abbreviations for several study areas: SB, Signal Butte area at Miles City; PH, Pine Hills area, near Locate; TB, Terry Badlands area, near Terry; LMR, Little Missouri River area; E, Ekalaka area; and CH, Cave Hills area, near Ludlow. CCA is Cedar Creek anticline; and MCA is Miles City arch.

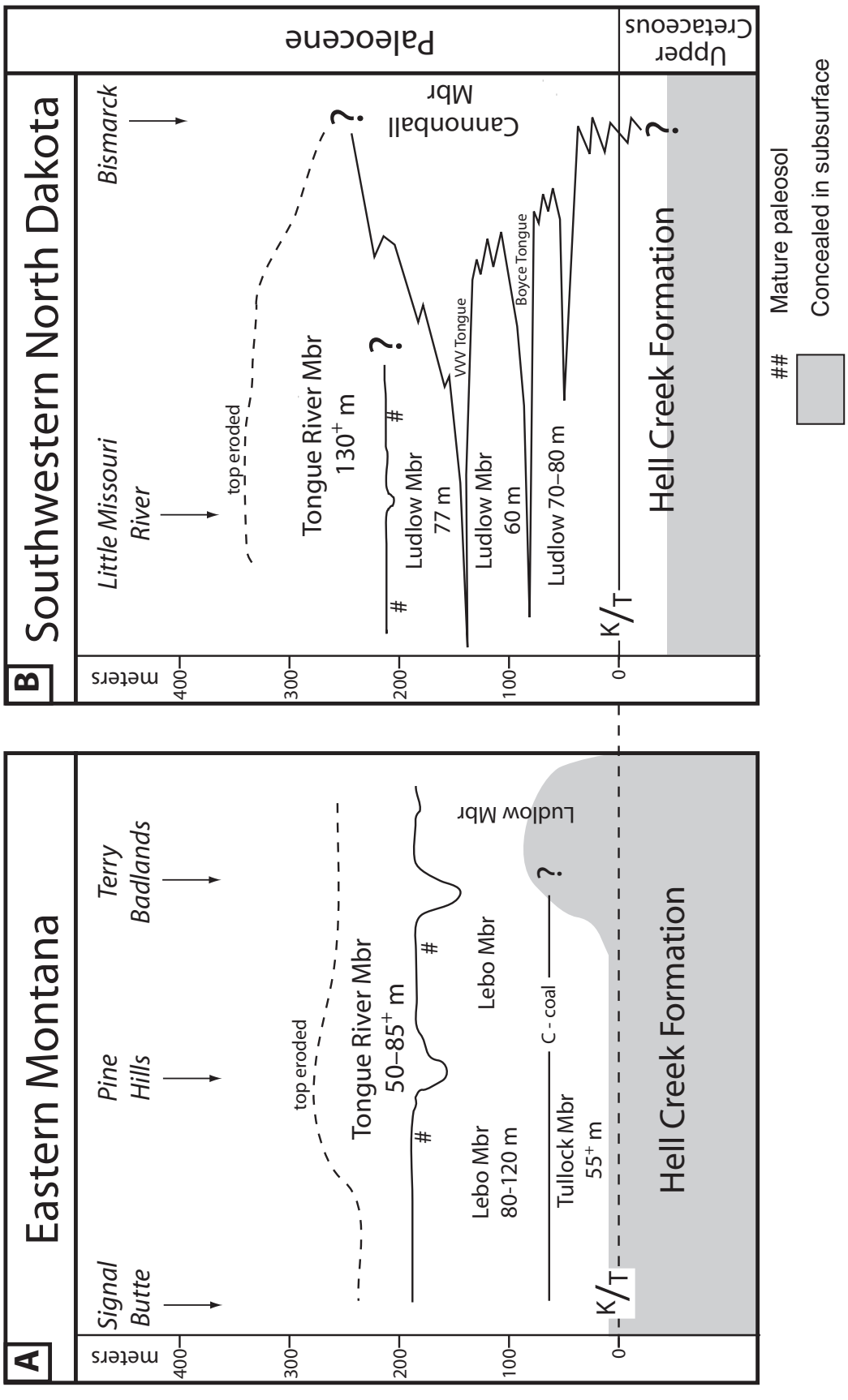


Figure 2. Stratigraphic succession in eastern Montana (*A*) compared with that of southwestern North Dakota (*B*); Cedar Creek anticline (Fig. 1) separates the areas. Unconformities, discussed by Belt et al. (2004), are not shown. Thicknesses of stratigraphic units are based on sections measured from outcrops (Belt et al., 1984, 1992; ESB, 1981–2002, unpublished data). No age equivalency of various members between (*A*) and (*B*) is intended. Cannonball Member of Fort Union Formation and its tongues are of marine origin; other members are largely, but not entirely, of nonmarine origin.

Strata of the Fort Union Formation in the western Williston Basin consist mostly of poorly consolidated sandstone and mudstone deposits; extrabasinal conglomerate and primary carbonate deposits are unknown. Intraformational conglomerate and secondary (diagenetic) carbonate beds and nodules are common.

The lower 85 m or more of the Tongue River Member, the focus of this report, contain multiple 2 to 4 m-thick, coarsening-upward sequences of mud and fine-grained, rippled, poorly consolidated sandstone beds. These sequences often terminate in laterally persistent coal and/or freshwater mollusk/ostracode-bearing beds (Figs. 3 and 4). Rare channel deposits are comprised of medium-grained, cross-bedded sand and sandstone units associated with intraformational pebbles of carbonate nodules, caliche, coal clasts, and fossils. The sandstone bodies are lenticular in cross section, they exhibit a shoestring geometry, and they have been attributed to deposits of river channels (Belt et al., 1992). The low sinuosity of those rivers indicates deposition on a low-gradient (*sensu* Schumm and Kahn, 1972) coastal plain that lay along the western margin of the Cannonball Sea (Belt et al., 1992).

ICHNOLOGY

We describe eight ichnogenera (Table 1) from four study areas (*SB*, *PH*, *TB*, and *LMR* of Fig. 1). These are recognized only in sandstone beds within unconsolidated strata of the Tongue River Member. The stratigraphic positions of the most important burrowed beds are shown on two cross sections (Figs. 3 and 4). Many of the well-sorted, fine-grained, quartz-rich sandstone beds are intensely burrowed. Current and oscillation cross-laminae are the main sedimentary structures within them, whereas those sandstones that are cross- and planar-bedded are mostly barren of both body and trace fossils. Many of the uppermost surfaces of the burrowed beds are penetrated by root traces from the overlying beds.

DESCRIPTIONS OF TRACE FOSSILS

Arenicolites

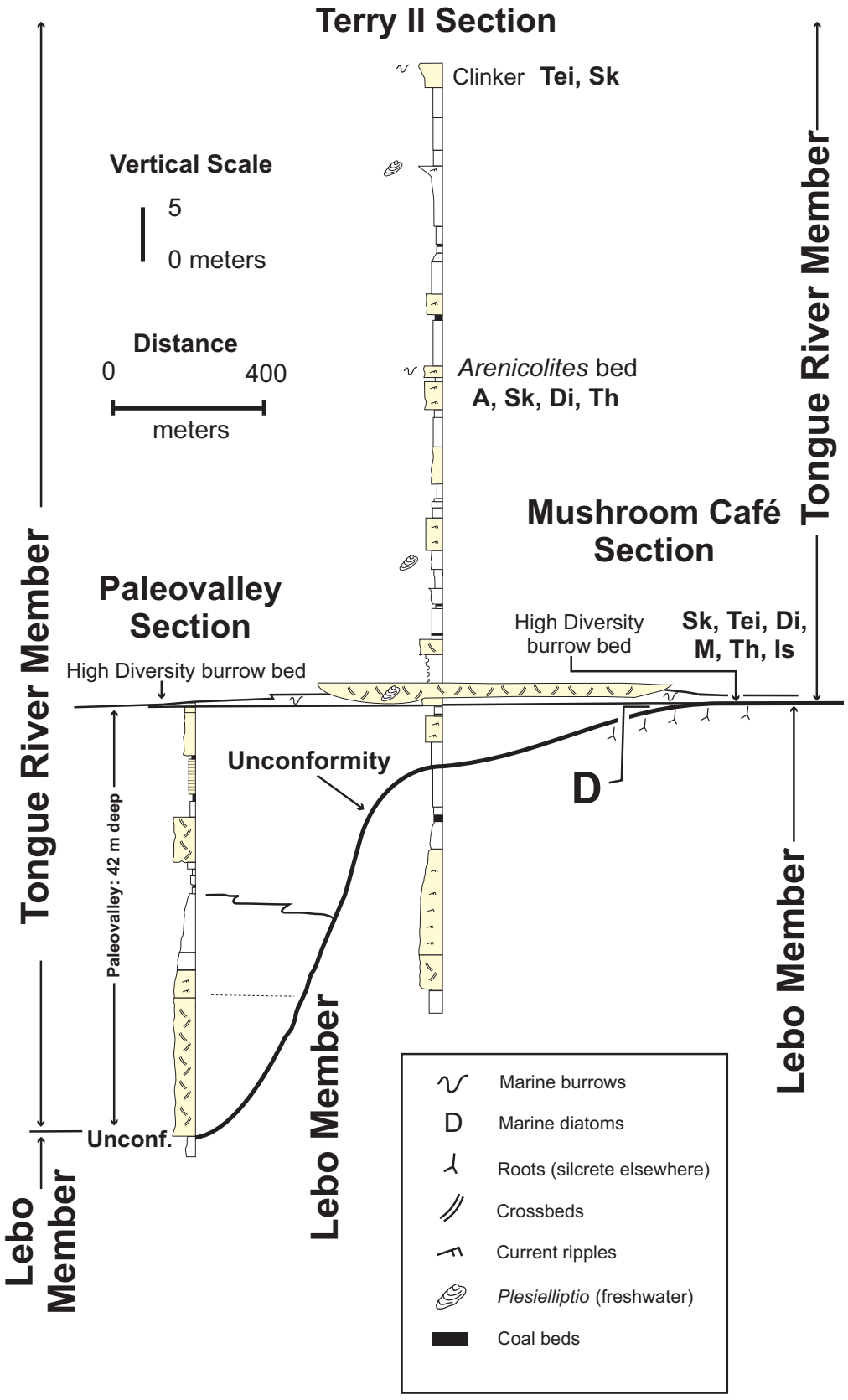
Figure 5*A–B*

Description.—Arenicolites is characterized by simple, vertical, U-shaped tubes that lack spreiten between the limbs. The outside diameter of the tubes typically measures about 0.5 cm, with the total depth of penetration into the substrate commonly exceeding 8–10 cm. The thin burrow walls are generally smooth and unornamented. One of the burrow limbs is faint or indistinguishable owing to specimen orientation and/or poor preservation. The resultant specimens of *Arenicolites* in the Tongue River Member therefore exhibit an overall J-shaped form. The distance between the two lateral tubes (when projected) is greater at the top than at the base, which results in a splayed appearance. The diagnostic flaring of the apertures is not observed, which we attribute to the erosion of the true burrow tops.

Occurrence.—Arenicolites occurs in a relatively high-diversity, burrowed bed (*Arenicolites* bed, Fig. 3, Table 1) 38 m above the base of the Tongue River Member in the Terry Badlands area. This bed is approximately one meter thick and consists of ripple- and cross-bedded, fine-grained sandstone (Table 1, Appendix 1, Terry-II, Unit 32). *Arenicolites* is associated with *Skolithos linearis*, *Thalassinoides,* and *Diplocraterion* (Fig. 3). *Arenicolites* also occurs in a low-diversity burrowed bed 54 m above the base of the Tongue River Member at the Pine Hills area (Fig. 2; Appendix 1, PH-B-33, Unit 30). This bed consists of ripple-laminated, fine-grained sandstone that is intercalated with units of mud.

Paleoenvironmental significance.—Arenicolites commonly is associated with sandy substrates in low-energy marine, shoreface, and tidal-flat environments. The burrows are attributed to either suspension/filter-feeding polychaetes or small crustaceans that created dwelling tubes in soft sediment (Pemberton et al., 2001).

Figure 3, facing page. Stratigraphic sections from Terry Badlands district. Terry II section lies 600 m east of Paleovalley section and approximately 600 m west of Mushroom Café section. Note especially: position of High Diversity ("Hi. D.") burrow bed and *Arenicolites* bed above base of Tongue River Member of Fort Union Formation; *Plesielliptio* in cross-bedded sandstone above Hi. D. bed; and a paleovalley filled by lower Tongue River Member that was incised into upper Lebo Member. Paleovalley depth (42 m) is measured from base of High Diversity burrow bed to base of sandstone in incised valley fill. Abbreviations represent trace fossils: A, *Arenicolites*; Di, *Diplocraterion*; Is, burrow of uncertain affinity ("Incertae sedis"); M, *Monocraterion*; O, *Ophiomorpha*; Sk, *Skolithos*; Tei, *Teichichinus*; and Th, *Thalassinoides*.


Terry II Section
Clinker Tei, Sk
Vertical Scale
5
0 meters
Distance
0
400
meters
Arenicolites bed
A, Sk, Di, Th
Tongue River Member
Mushroom Café Section
Paleovalley Section
High Diversity burrow bed
High Diversity burrow bed
Sk, Tei, Di, M, Th, Is
Unconformity
D
Paleovalley: 42 m deep
Unconf.
Lebo Member
Lebo Member
Lebo Member
Tongue River Member
Marine burrows
D Marine diatoms
Roots (silcrete elsewhere)
Crossbeds
Current ripples
Plesielliptio (freshwater)
Coal beds

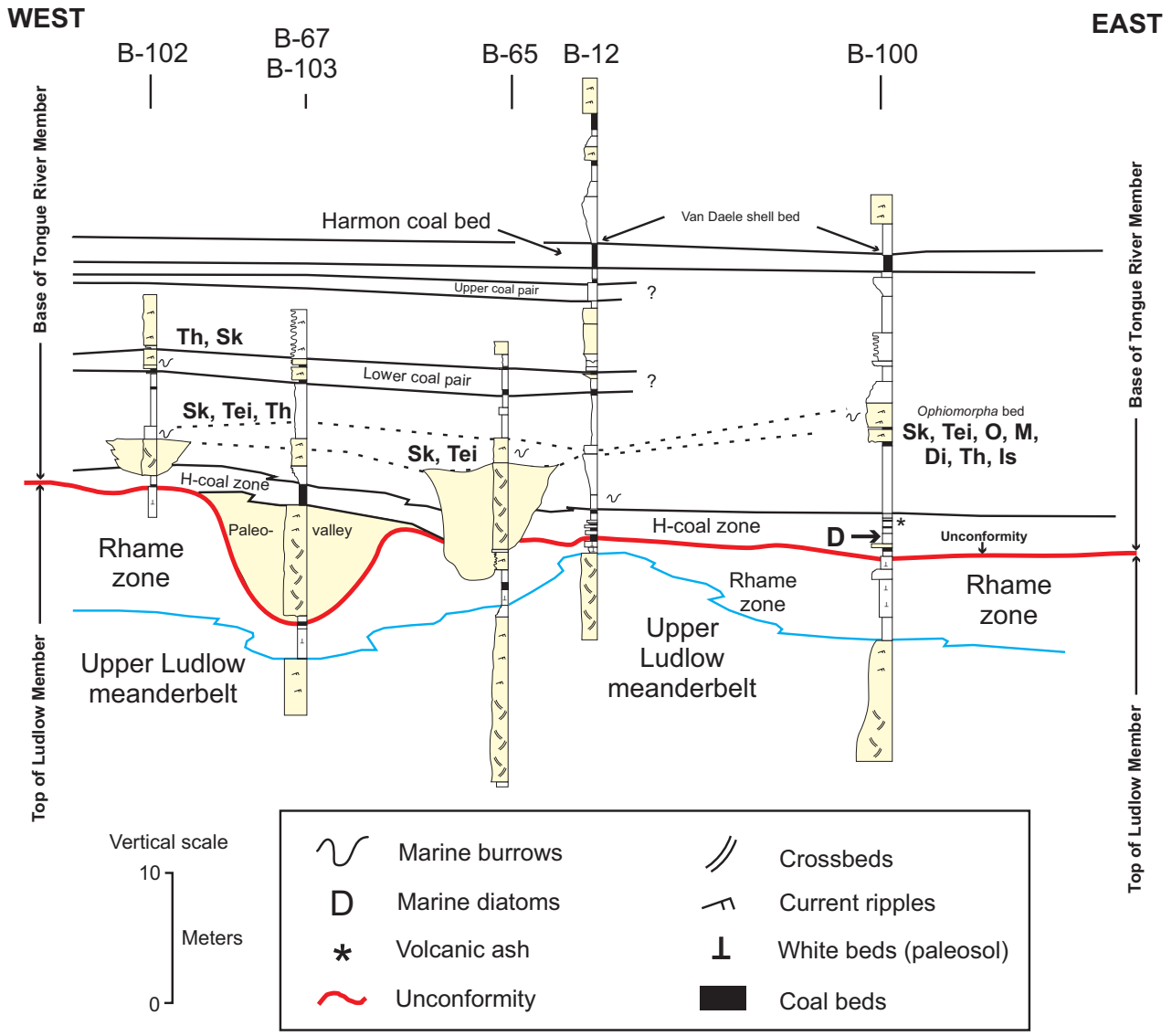


Figure 4. Correlation of stratigraphic sections from Little Missouri River area. The Harmon coal bed and overlying Van Daele shell bed are correlation units. Note presence of marine diatom bed in H-coal zone. Abbreviations as in Figure 3. Distance from B-102 to B-100 is 3 km.

Diplocraterion

Figure 5*C*

Description.—Diplocraterion comprises shallow, U-shaped tubes (concave up) with protrusive spreiten and an orientation subvertical to bedding. Deeper burrows (<5 cm) tend to deviate from the vertical by approximately 10° (Fig. 5*C*). The diameter of the lateral tubes is approximately 0.5 cm, and the distance between limbs of the burrows is 2 to 3 cm, with a 10 cm maximum depth of penetration. Diagnostic funnel-shaped tops to the burrows, as described by Häntzschel (1975, p. W62), were not observed. Only protrusive spreiten were observed, although retrusive spreiten are not uncommon for this ichnogenus (Goldring, 1962).

Occurrence.—Diplocraterion occurs in the Little Missouri River area (Fig. 4; Appendix 1, LMR-B-100, Unit 22 and LMR-B-12, Unit 15) in the *Ophiomorpha* bed. In addition to *Diplocraterion* (two sites were found, 600 m apart), that bed contains

Table 1. List of ichnogenera and their corresponding localities. Very abundant (VA), abundant (A), common (C), and rare (R) indicate relative abundance of burrows at each locality. bbb, basal burrowed bed, occurs at each locality except Terry Badlands.

	Signal Butte	Terry Badlands			Pine Hills			Little Missouri River		
Trace Fossil	bbb	*Monocraterion* bed	High Diversity burrow bed	*Arenicolites* bed	bbb	*Rhizocorallium* bed	*Arenicolites* bed	bbb	*Ophiomorpha* bed	Lower coal pair interval
Arenicolites				VA			R			
Diplocraterion			R	R					R	
Monocraterion		A	R						R	
Ophiomorpha									A	
Rhizocorallium						R				
Skolithos linearis	R	A	C	C	C	R	R	C	A	C
Teichichnus	A	R	C		C	R	R	C	C	C
Thalassinoides		R	R	R		R			R	
Burrow of uncertain affinity		R	R							

Skolithos linearis, Teichichnus, *Thalassinoides,* and *Monocraterion* (Fig. 4). *Diplocraterion* also occurs in the Terry Badlands (Fig. 3; Appendix 1, Terry II, Unit 13) at the Mushroom Café locality within the High Diversity (Hi. D.) burrow bed. At this locality, overlying strata were eroded away within a half-kilometer area thus exposing the burrowed sandstone bed. *Diplocraterion* also is present in the Ekalaka Member (Belt et al., 1997) in the Ekalaka area (*E*, Fig. 1).

Paleoenvironmental significance.—Diplocraterion is common within modern marine sandy tidal flats, estuarine channel deposits, and in marine-shoreface settings. These dwelling burrows can be formed by a variety of marine organisms, including suspension-feeding polychaetes (Pemberton et al., 2001).

Monocraterion

Figure 5*D*

Description.—Monocraterion is characterized by unbranched, straight to gently curved, vertical burrows with wide, funnel-shaped tops. Thin burrow linings are present. Burrow diameters range from 0.3–0.5 cm at the base, increasing to widths of 0.5–2 cm at funnel tops. Burrow lengths average 6–10 cm. Figure 5*D* illustrates the wide burrow top and the typical numerous, closely spaced vertical tubes. This

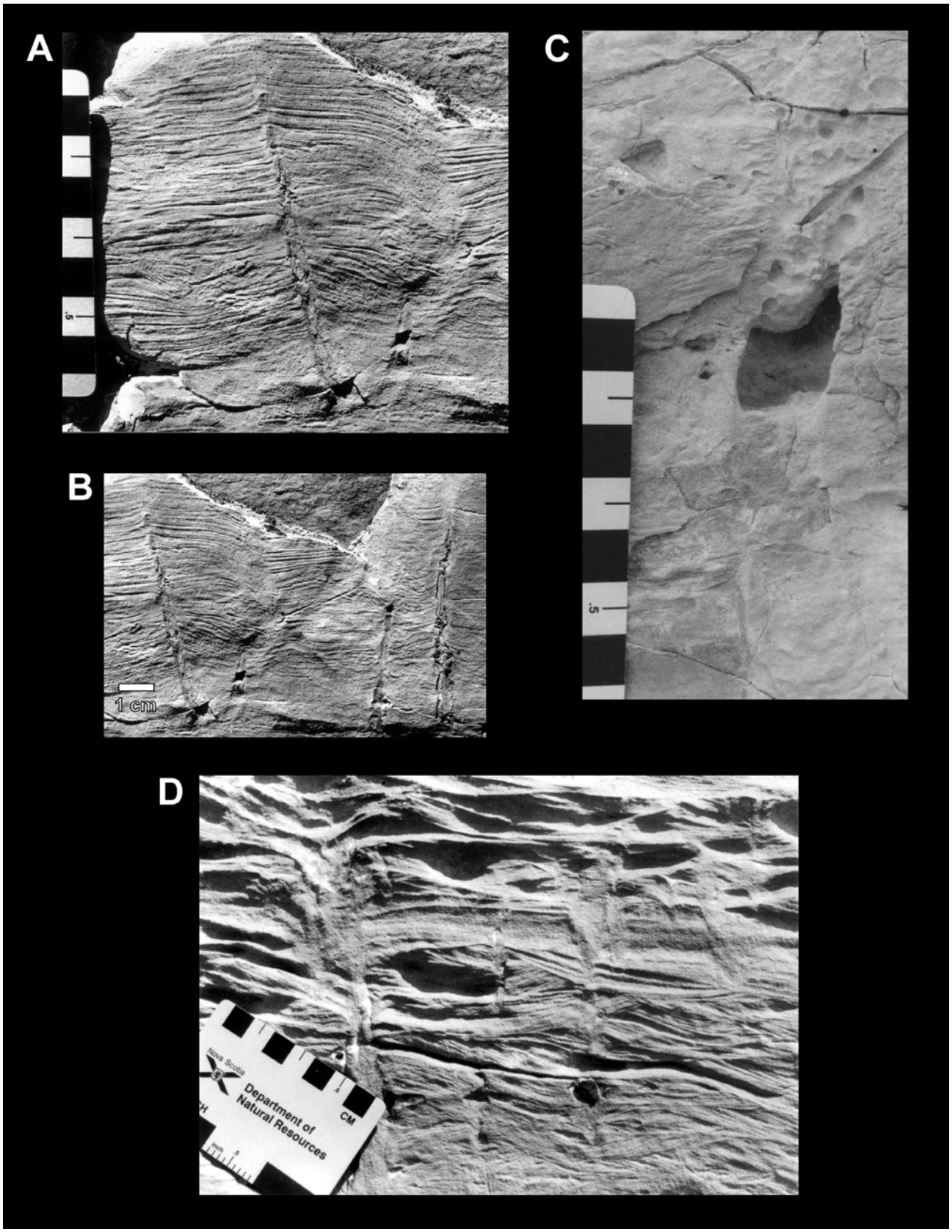

A
B
1 cm
C
D
Nova Scotia
Department of
Natural Resources
CM

Figure 5, facing page. Photographs of *Arenicolites*, *Diplocraterion*, and *Monocraterion*. ***A*** and ***B***, *Arenicolites* bed (Fig. 3; Appendix 1, Terry-II, Unit 32), Terry Badlands. *A* is an enlarged view of part of face shown in *B*; latter view shows other representatives of this trace fossil. Note in *A* that the burrow is J-shaped. Specimens of *Arenicolites* at this locality consist of very fine-grained sandstone that has been replaced largely by micrite. Laminae exhibit wavy structure, representing the foreset cross-laminae of current ripples and also climbing ripples. Scale in centimeters. ***C***, Vertical view of *Diplocraterion* in Hi. D. burrow bed, Terry Badlands district (Fig. 3; Appendix 1, Terry-II, Unit 6). This bed consists of yellow, very fine-grained, current-rippled sandstone. Scale in centimeters. ***D***, *Monocraterion* in vertical view in *Monocraterion* bed , Signal Butte, Miles City, Montana (Appendix 1, section SB-II, Unit 52). This bed consists of very fine-grained, yellow, current-rippled sandstone. Scale in centimeters.

observation indicates that pulses of intense burrowing were separated by intervals of less intense burrowing.

Occurrence.—Specimens of *Monocraterion* were found at Signal Butte, Terry Badlands, and the Little Missouri River study areas. The burrowed bed at Signal Butte is named the *Monocraterion* bed because of the high relative abundance of trace fossils (Table 1). This bed occurs 31 m above the base of the Tongue River Member (Appendix 1, SB-II, Unit 52). *Monocraterion* also is found in the Hi. D. burrow bed at the Mushroom Café locality, Terry Badlands area (Fig. 3) and in the *Ophiomorpha* bed, Little Missouri River area (Fig. 4; Appendix 1, LMR-B-100, Unit 22).

Paleoenvironmental significance.—Specimens of *Monocraterion* from the Tongue River Member are similar to those reported in marine sandstones of the Upper Mannville Group (Lower Cretaceous) of Alberta, Canada (Wightman et al., 1987, fig. 22). The builder of this trace fossil riddled the substrate at Signal Butte. Barwis (1985) made a convincing case that the modern polychaete *Diopatra cuprea* is a reasonable analog for both *Monocraterion* and *Skolithos.* This polychaete constructs lined, vertical tubes in a wide range of restricted and open-marine environments, including intertidal settings.

Ophiomorpha

Figure 6*A*

Description.—*Ophiomorpha* is characterized by branching, three-dimensional burrow systems that comprise shafts and tunnels containing well-developed linings of agglutinated sediment. Burrow linings are smooth on the interior and they are characteristically pelleted on the exterior. Burrow systems range from simple to complex, with irregularly spaced, Y-shaped branches. Outside burrow diameters are 1.0 cm or only slightly greater. The burrow walls are 1–2 mm thick with smooth interiors and mammalated exteriors. The poorly formed pellets are approximately 2 mm in diameter. Some burrows have unequal pellet distribution, and isolated parts of the burrow system have smooth, thin walls; this is common for *Ophiomorpha* (see Frey et al., 1978). Y-shaped branches are found in the *Ophiomorpha* bed in the Little Missouri River area (Fig. 4).

Occurrence.—This trace fossil was found by ESB in the Tongue River Member (Fig. 4; Appendix 1, LMR-B-100, Unit 22 and LMR-B-56, Unit 16) and by van Alstine (1974) in the much older Three V Tongue of the Cannonball Member (both sites in the Little Missouri River area). *Ophiomorpha* also was reported from the Ekalaka Member (Belt et al., 1997) in the Ekalaka area (Fig.1). At section LMR-B-100 (Fig. 4), *Ophiomorpha* occurs in poorly lithified, rippled, fine-grained sandstone. Tabular cross beds with rhythmic silt drapes also occur in this unit, and these indicate bidirectional, possibly tidal, current activity (Belt et al., 1983).

Paleoenvironmental significance.—*Ophiomorpha* is common in marine sandy substrates, and elaborate burrow systems often are prolific in shoreface environments (Frey et al., 1978). Occurrences in brackish-water settings include estuaries and tidal shoals. These dwelling burrows were created by decapod crustaceans, most commonly callianassid shrimp (Frey et al., 1978; Pemberton et al., 2001).

Rhizocorallium

Figure 6*B*

Description.—*Rhizocorallium* is characterized by simple, U-shaped structures with protrusive spreiten that lie between parallel tubes whose diameters are about 4 mm. The burrows are oriented subparallel to bedding, with widths of 2.5 cm and lengths that may exceed 12 cm. Upward-curving burrow components that cut across bedding were not observed. The vertical orientation of *Diplocraterion* is a useful characteristic (Chisholm, 1970; Ekdale et al., 1984, figs. 2–4; Chaplin, 1996, figs. 19–21) to distinguish it from *Rhizocorallium*.

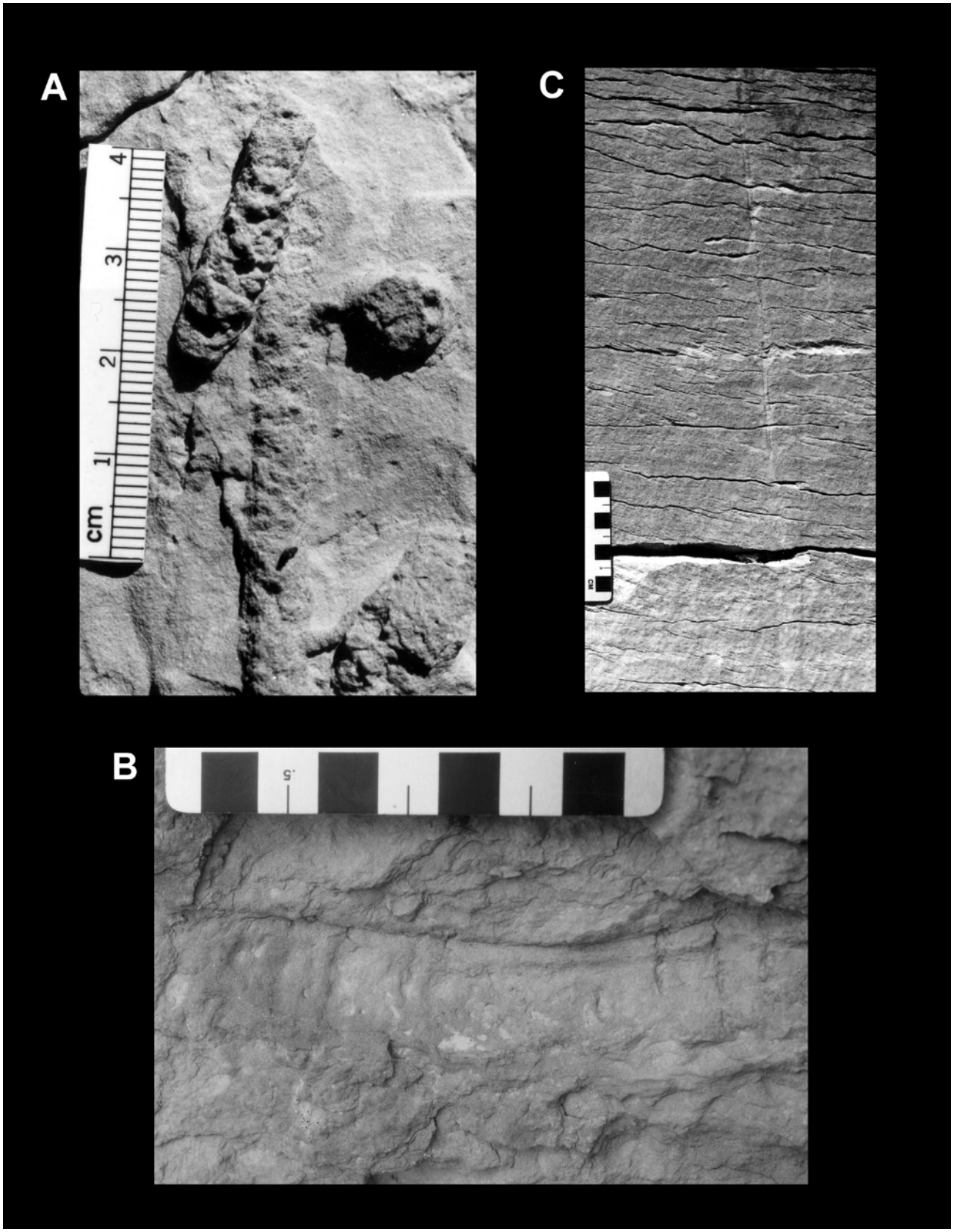

A
cm
1
2
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Figure 6, facing page. Photographs of *Ophiomorpha*, *Rhizocorallium*, and *Skolithos*. ***A***, *Ophiomorpha* on a bedding surface in *Ophiomorpha* bed, Little Missouri River area, North Dakota (Fig. 4; Appendix 1, LMR-B-100, Unit 22). Note tunnels and cross section of a shaft. Tunnel next to scale is at a 45° angle to bedding surface. This bed consists of yellow, very fine-grained, current-rippled and tabular cross-bedded sandstone. ***B***, Bedding-plane view of specimen of *Rhizocorallium* from Pine Hills area, near Locate, Montana (Appendix 1, PH-B-31, Unit 28). This bed is a yellowish, fine-grained, muddy sandstone. Scale in centimeters. ***C***, Well developed *Skolithos linearis* from the Hi. D. burrow bed, Mushroom Café section, Terry Badlands area, near Terry, Montana (Fig. 3; Appendix 1). Burrow was at least 38 cm deep. Lithologic composition is yellowish, fine-grained, ripple-laminated sandstone.

Occurrence.—Rhizocorallium was found only at the top of Unit 28 in section PH-B-31 the Pine Hills area (Appendix 1). This unit is referred to as the *Rhizocorallium* bed (Table 1); it has not been recognized in the Signal Butte, Terry Badlands, or Little Missouri River areas.

Paleoenvironmental significance.—Rhizocorallium commonly occurs in sandy substrates of shallow-marine, subtidal settings (Chisholm, 1970, p. 47–49; Belt, 1975, 1984), where the dwelling burrows were created by deposit-feeding invertebrates (Häntzschel, 1975; Bromley, 1996).

Skolithos linearis

Figures 6*C* and 7*A*

Description: Skolithos linearis is characterized by vertical to steeply inclined, straight, unbranched cylindrical to subcylindrical burrows that have thin wall linings. It is a simple dwelling burrow. Individual burrows can be traced for lengths of 20–38 cm (Fig. 6*C*). Tube diameters typically range from 2 to 3 mm. Burrow linings are distinct and thin. Typical spacings between individual burrows of *Skolithos linearis* range from 30 to 60 cm. Specimens that yield an oxidation halo can be mistaken for rootlets.

Occurrence.—Skolithos linearis is found at all four of the study areas and in all units that are formally regarded as "burrow beds" (Table 1). It is also common in the Ekalaka Member (Belt et al., 1997) in the Ekalaka area (*E*, Fig. 1).

Paleoenvironmental significance.—Skolithos linearis occurs in a wide range of paleoenvironmental settings, from deep-water to shallow-water marine. Lined burrows are thought to be associated with marine to brackish environments (Wightman et al., 1987; Pemberton et al., 2001). The living marine polychaetes *Onuphis microcephala* (see Curran and Frey, 1977; Belt et al., 1983) and *Diopatra cuprea* (see Barwis, 1985) are among the best modern analogues.

Irregular forms of *Skolithos* that rarely exceed 10 cm in length were described and discussed by Belt et al. (1997), who used the designation "*Skolithos*". They were the only trace fossils found in upper parts of the Ludlow Member in the Ekalaka section. Elsewhere in the Ekalaka and the Tongue River Members, they occur in association with *S. linearis*, where they are considered as an indicator for low-salinity conditions (Belt et al., 2002).

Teichichnus

Figure 7*B–C*

Description.—In vertical sections (Fig. 7*B*), *Teichichnus* most commonly appears as a series of tightly packed, concave upward, crescentic laminae. Bedding-plane surfaces reveal unbranched, sinuous burrows that are approximately 0.5–1.5 cm in width (Fig. 7*C*). Burrow lengths range from 30 to 80 cm. In some cases, there is an apparent superposition of one burrow over another. The largest specimens of *Teichichnus* (0.5–1.0 cm) occur in beds in which ichnogeneric diversity is relatively high.

Occurrence.—Teichichnus is widespread at all four of the study areas and in all units designated as a "burrow bed" (Table 1). Curiously, it was not recognized in the Ekalaka Member in the Ekalaka area (Belt et al., 1997).

Paleoenvironmental significance.—Pemberton et al. (2001, p. 324) considered *Teichichnus* as an indicator for lower marine shoreface, offshore-marine environments and brackish-water, lagoonal and bay facies. Given the long geologic range of this ichnogenus, *Teichichnus* tracemaker organisms probably represent a variety of deposit-feeding worm or worm-like invertebrate groups (Häntzschel, 1975; Pemberton et al., 2001).

Thalassinoides

Figure 7*D*

Description.—Thalassinoides is characterized by three-dimensional burrow systems that comprise smooth-walled, cylindrical segments with Y- to T-shaped branching. The unlined burrows are approximately 1.0 to 2.5 cm in diameter. The larger diameter

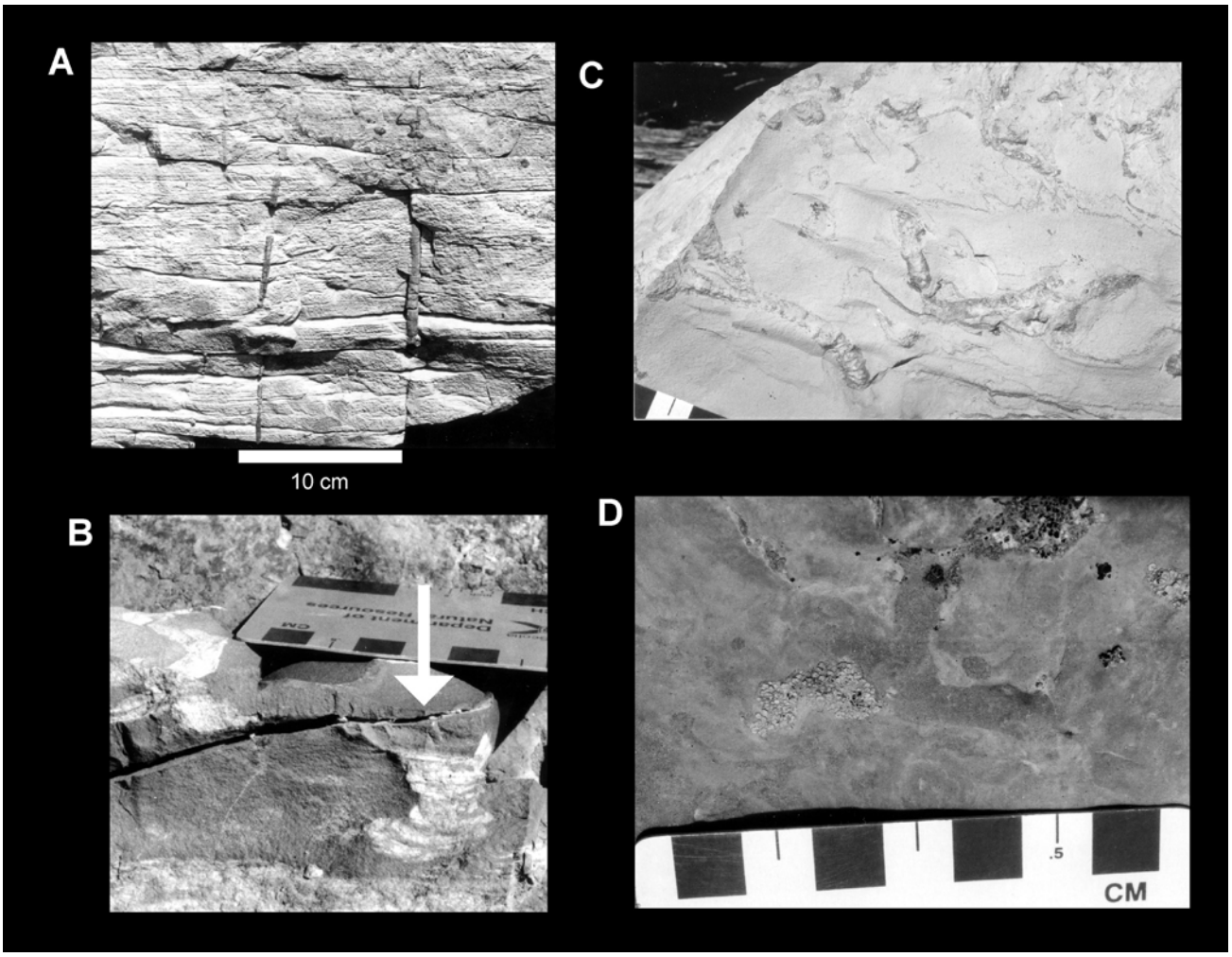

Figure 7. Photographs of *Skolithos linearis*, *Teichichnus*, and *Thalassinoides*. ***A***, *Skolithos linearis* in *Monocraterion* bed, Signal Butte, Montana (Appendix 1, SB-II, Unit 52). See Figure 5D for lithologic description of this bed. Scale in centimeters. ***B***, *Teichichnus* in vertical view of Hi. D. burrow bed, Mushroom Café locality, Terry Badlands. The 2-cm width of these burrows contrasts with <1 cm width of burrows from Signal Butte district (Fig. 7C). Mushroom Café burrows come from a bed of high diversity, indicating polyhaline conditions (Table 1). Lithologic composition is yellowish, fine-grained, rippled sandstone cemented by calcite. Scale in centimeters. ***C***, *Teichichnus* exposed on bedding plane from basal burrow bed (bbb) at Signal Butte (Appendix 1, SB-II, Unit 13). Signal Butte burrows come from a unit of low diversity, indicating oligohaline conditions (Table 1). Lithologic composition is yellowish, very fine-grained, ripple-laminated sandstone replaced by micrite. Scale in centimeters. ***D***, *Thalassinoides*, vertical view in Hi. D. burrow bed, Mushroom Café section, Terry Badlands, near Terry, Montana (Fig. 3). Note lack of burrow wall and Y-shaped branch. Lithologic composition is yellowish, fine-grained, ripple-laminated sandstone. Scale in centimeters.

is associated with beds of higher diversity (Table 1).

Occurrence.—Thalassinoides occurs in five beds of the Tongue River Member. Three of these include the *Monocraterion* bed at Signal Butte (Appendix 1, SB-II, Unit 52), the High Diversity (Hi. D.) burrow bed at Terry Badlands (Fig. 3; Appendix 1, Mushroom Café locality), and in the *Ophiomorpha* bed in the Little Missouri River area (Fig. 4; Appendix 1, LMR-B-100, Unit 22). *Thalassinoides* is rare at most other localities (Table 1). It occurs in the Ekalaka Member (Belt et al., 1997) in the Ekalaka area.

Paleoenvironmental significance.—Thalassinoides is common in lower marine shoreface to offshore environments, but it also is known to occur in brackish-water environments associated with low ichnogeneric diversity (Pemberton et al., 2001). *Thalassinoides* is

regarded as a dwelling/feeding burrow of a deposit-feeding thalassinid shrimp (Myrow, 1995).

Burrow of uncertain affinity
Figure 8*A*

Description.—This trace fossil comprises unbranched, cylindrical, gently curved burrows that are commonly oblique to bedding. The burrow-fill typically has a meniscate structure. Burrow diameter is approximately 1 cm, and the burrow lengths typically exceed 8 cm.

Occurrence.—A single specimen of this burrow occurs in the *Monocraterion* bed at Signal Butte (Appendix 1, section SB-II, Unit 52), and two additional specimens occur in the High Diversity (Hi. D.) burrow bed, Terry Badlands (*Is*, Fig. 3; Mushroom Café section; Table 1).

TAXONOMY OF BODY FOSSILS

The following section presents abbreviated taxonomic notes for diatoms, bivalves, and ostracodes collected from the Tongue River Member. Bivalve classification follows Hartman and Anderson (2002) and Anderson et al. (*in review*). Ostracode descriptions follow the classification scheme modified from Benson et al. (1961).

Class DIATOMACEAE
Coscinodiscus spp.
Figure 9*A–F*

Remarks.—Specimens of *Coscinodiscus* from the Tongue River Member resemble the Paleocene species *Coscinodiscus morsianus* (Grunow) Sims (cf. Sims, 1989). Figures 9*A* and 9*B* show two specimens that bear overall similarity to *C. morsianus* in external morphology, including the irregularly branched pattern of rows of areola, many of which are incomplete and terminate at different locations on the valve face. Examination of the internal structure by scanning-electron micros-

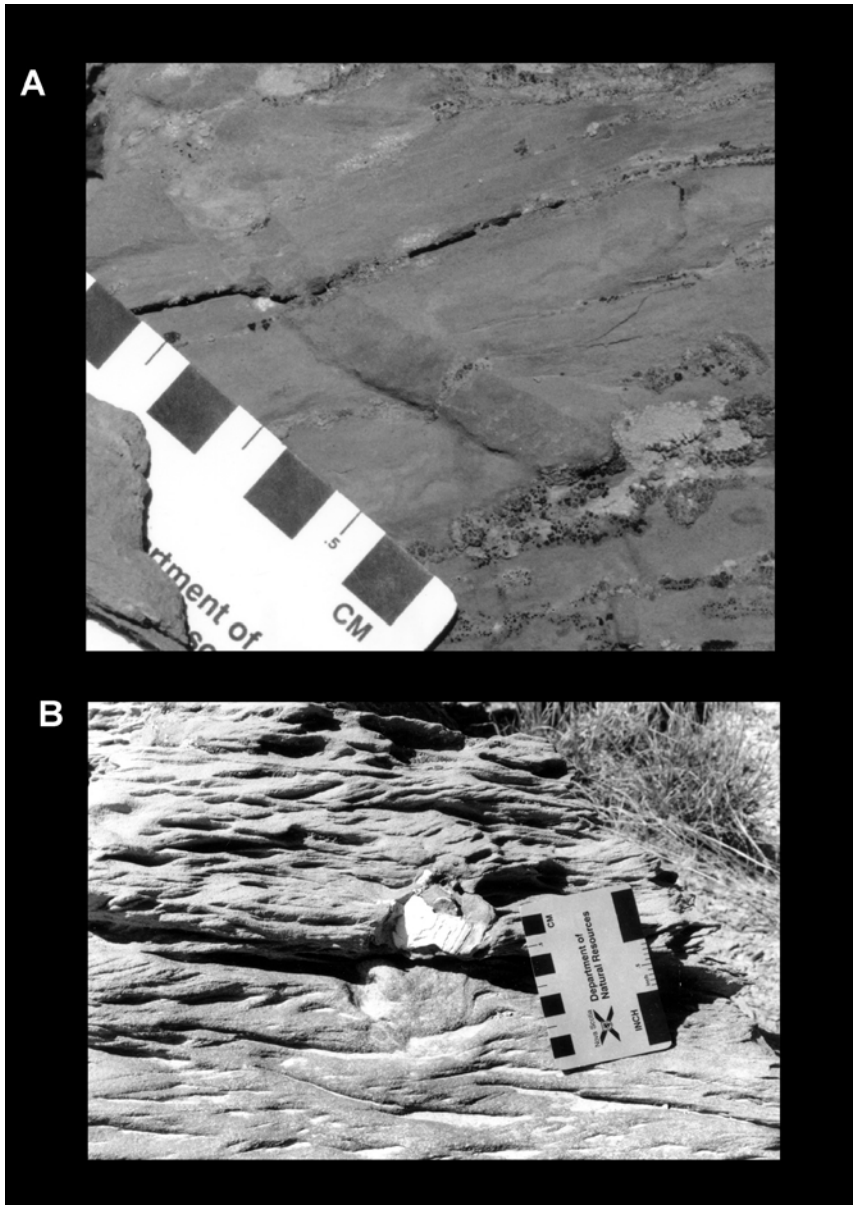

Figure 8. ***A***, Trace fossil of uncertain affinity from Hi. D. burrow bed, Mushroom Café section, Terry Badlands, near Terry, Montana (Fig. 3; Appendix 1, Terry-II, Unit 6). This burrow cuts diagonally across bedding. Note internal meniscus structure. The High Diversity burrow bed here consists of yellowish, fine-grained, ripple-laminated sandstone. Burrow is horizontal to slightly oblique to bedding surface. ***B***, Partially intact shell of *Plesielliptio*, a fresh water bivalve, shown in its resting/escape burrow in a river-channel deposit that cuts into High Diversity burrow bed, Mushroom Café, Terry Badlands. Channel deposits are gray, medium-grained, ripple cross-laminated sandstones. Vertical to oblique surface; scale on left in centimeters, on right in inches.

copy would be required to observe the diagnostic presence of a tightly spaced linear zone of labiate processes. It is also possible that the specimens represent *C. fulguralis* Brun (cf. Strelnikova et al., 1998). One of the specimens of *Coscinodiscus* recovered from the Little Missouri River area (Fig. 9*C–F*) has been identified tentatively as *Coscinodiscus marginatus* Ehrenberg.

Occurrence.—Specimens of *Coscinodiscus* were recovered from thin stratigraphic intervals at two sites 140 km apart. The more westerly site is the Mushroom Café locality (Fig. 3) in the Terry Badlands, just 20 cm below the High Diversity burrow bed at the base of the Tongue River Member. The more easterly site is 2 m above the base of the Tongue River Member

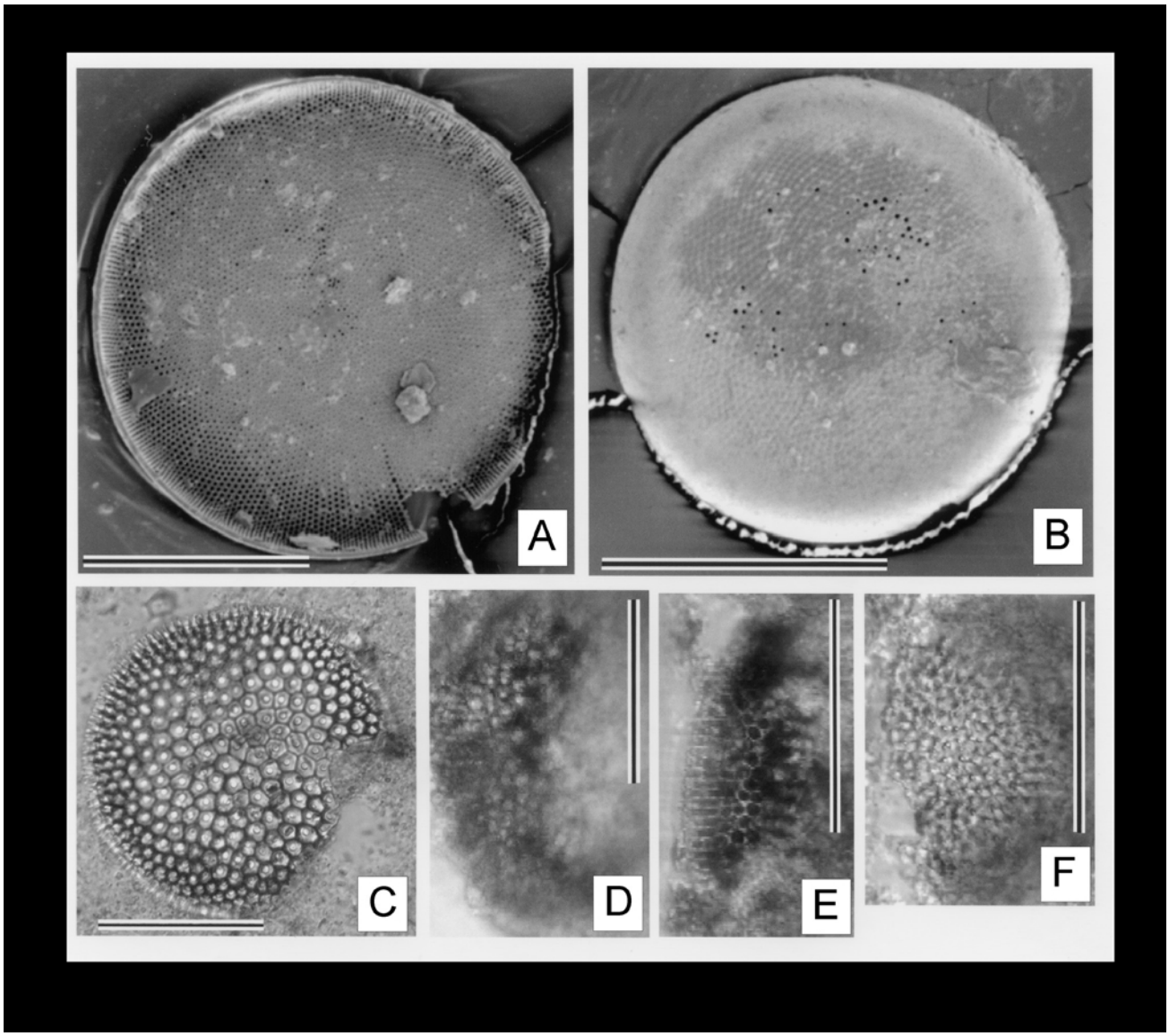

Figure 9. ***A–B***, Photographs of marine diatoms *Coscinodiscus morsianus*? from Tongue River Member, Terry Badlands (Fig. 3). ***C–F***, Photomicrographs of marine diatoms *C. marginatus* Ehrenberg (sample KB-01-27) from Tongue River Member, Little Missouri River district (Fig. 4). Specimens shown in *D–F* are highly dissolved remnants of valves, emphasizing structures of margins. Scale bars: *A–B*, 100 microns; and *C–F*, 50 microns. Specimens are poorly preserved and sparse, suggesting that they may have been washed into local settings during storm surges.

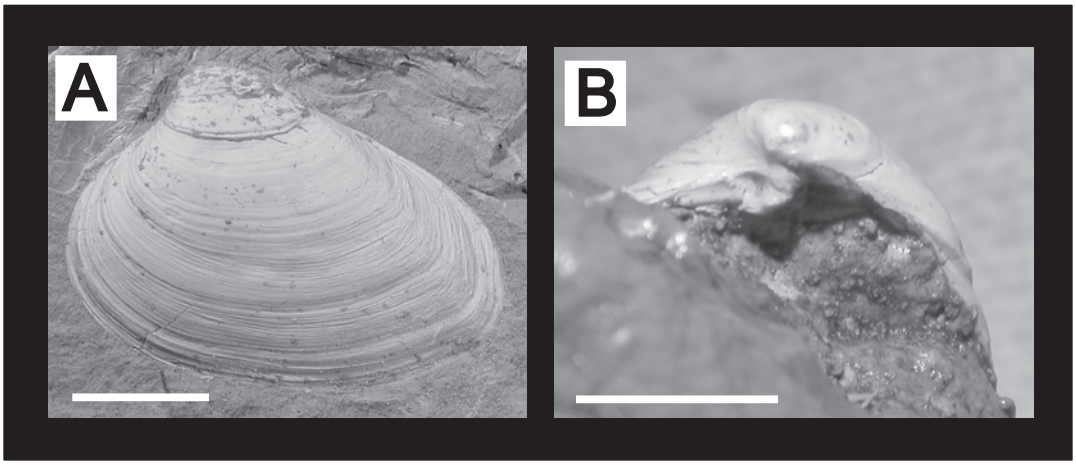

Figure 10. Photographs of shells of *Pachydon mactriformis* Meek and Hayden from the Van Daele shell bed, Section B-56 (Belt et al., 2004, fig. 9), Little Missouri River district. ***A***, Exterior view of right valve. ***B***, Cardinal tooth in a right valve. Scale bars 5 mm.

within the H-coal Zone (Fig. 4; Appendix 1, section LMR-B-100, Unit 14). The two beds do not correlate (Belt et al., 2004).

Paleoenvironmental significance.—*Coscinodiscus* is a widespread marine genus, known from the late Cretaceous to Holocene in neritic and oceanic environments (Sims, 1989; Makarova, 1993; Strelnikova et al., 1998). Expected normal-marine assemblages would also include *Hemiaulus*, *Trinacria*, *Sheshukovia*, and *Stephanopyxis* (e.g., Harwood, 1988; Fenner, 1994; Tapia and Harwood, 2002). Their absence in the Tongue River samples is attributed to a combination of lower-salinity depositional conditions and to post-burial, taphonomic dissolution of these small, delicate marine species. *Coscinodiscus* has not been reported from Upper Cretaceous, nonmarine deposits in Mexico (Chacon-Baca et al., 2002), thus a low-salinity (nonmarine) interpretation of the early Paleocene Tongue River Member is difficult to justify. We therefore regard these specimens as brackish representatives of a restricted marine environment.

Class BIVALVIA

Superfamily MYOIDEA

CORBULIDAE Lamarck, 1801

Pachydon Gabb, 1869

Pachydon mactriformis (Meek and Hayden, 1856)

Figure 10*A–B*

Corbula mactriformis Meek and Hayden, 1856, p. 117.

Corbula (*Pachydon) mactriformis* Meek and Hayden: Meek and Hayden, 1856, pl. 43, figs. 7*a–e* (holotype), p. 345–346.

Bicorbula mactriformis (Meek and Hayden) Cvancara, 1965, pl. VIII, figs. 1–3, p. 528.

Pachydon mactriformis (Meek and Hayden): Hartman and Anderson, 2002, p. 355.

Remarks.—Extended remarks on the nomenclatural history of *Pachydon* in South America and *Pachydon mactriformis* in North Dakota can be found in Anderson et al. (*in review*). Diagnostic features of the genus include a prosogyrous umbo and beak (Fig. 10*B*), a strong cardinal tooth that is bluntly rectangular (in the right valve, Fig. 10*B*), a strong keel (especially in the left valve), and fine concentric striae on valve surfaces (Fig. 10*A*). Species of *Pachydon* commonly exhibit a deeply impressed and rugose anterior adductor muscle scar, a nonplanar commissure, a chondrophore, and a cardinal tooth (Anderson et al., *in review*).

Pachydon mactriformis was originally described by Meek and Hayden (1856) and then re-described with more modern terminology by Cvancara (1965). Meek (1876) recognized the morphological similarity to *Pachydon*, a genus having been described by Gabb (1869), by assigning *P. mactriformis* to Gabb's (1869)

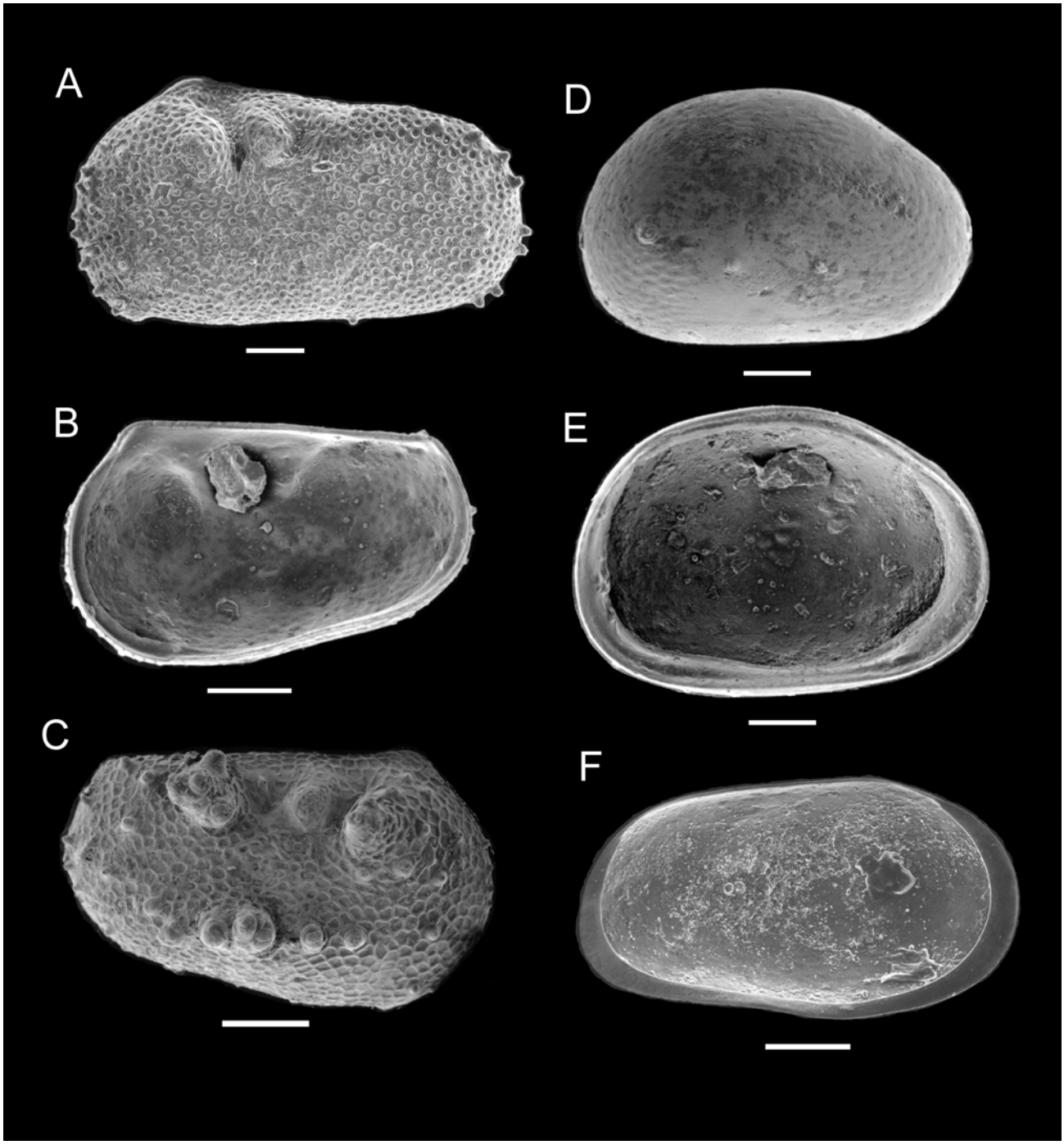

Figure 11. Photographs of valves of ostracodes *Bisulcocypridea arvadensis* (Swain, 1949), *Cypridopsis*, and *Candona*. ***A–C***, *B. arvadensis*; left lateral adult, right internal adult, and juvenile right external valve with nodes, respectively (specimens recovered from Van Daele shell bed in association with *Pachydon mactriformis*). ***D–E***, *Cypridopsis*; lateral (note slight reticulation) and internal views of adult valves, respectively. ***F***, *Candona*; internal aspect of disarticulated left valve. Scale bars 100 microns.

subgenus *Corbula*.

Occurrence.— *Pachydon mactriformis* defines the Van Daele shell bed (Fig. 4) above the Harmon coal bed in the Little Missouri River area. This bed appears in four sections (Appendix 1, sections LMR-B-12, B-100A, B-14, and B-56) that were illustrated by Belt et al. (2004) in their figures 8 and 9; the sections span a distance of 14 km from west to east.

Paleoenvironmental significance.—Anderson et al. (*in review*) consider *Pachydon mactriformis* to be a freshwater representative of a family previously known to include only marine and brackish species. In the Tongue River Member, *P. mactriformis* occurs with nonmarine ostracodes and freshwater sphaerid bivalves, and this association indicates a freshwater environment. However, other species of *Pachydon* also occur in marine deposits of the Cannonball Member in central North Dakota (Cvancara, 1965). *Pachydon mactriformis* occurs at 43 localities, where it is associated with freshwater bivalves in the Ludlow and Tongue River Members in western North Dakota and at two localities in the Ravenscrag Formation near Estevan, Saskatchewan. The species is interpreted as late Paleocene in age on the basis of co-occurrence (or stratigraphic correlation) of *P. mactriformis* with age-diagnostic mammalian faunas.

Class OSTRACODA
Order PODOCOPIDA
Suborder PODOCOPINA
Superfamily CYPRIDOIDEA
CYPRIDAE Baird, 1846
CYCLOCYPRIDINAE Kaufmann, 1900
Cypridopsis Brady, 1868
Cypridopsis sp.

Figure 11*D–E*

Description.—This subovate, medium to large ostracode is thinly to moderately calcified. The inner margin is characterized by a narrow inner lamella that is widest in the posterior and anterior ventral regions. The adductor-muscle scar field comprises four large stigmata organized into a sub-oblique to vertical array. The carapace is commonly reticulate and small pustules are common.

Remarks.—Brouwers and DeDeckker (1993) illustrated a species of *Cypridopsis* from Danian nonmarine strata in Alaska that resembles the taxon described here.

Occurrence.—Geographic, paleoecological, and stratigraphic distribution is the same as for *Bisulcocypridea arvadensis*.

CYPRINAE Sars, 1928
Candona Baird, 1850
Candona sp.

Figure 11*F*

Remarks.—This medium-sized ostracode is characterized by a finely calcified, delicate shell. The contact margin is defined by a wide, inner lamella, and there is a pronounced vestibule. Swain (1949, 1999) illustrated species of *Candona* from the Paleocene Fort Union Formation, and the archived material we have will require further taxonomic consideration.

Occurrence.—Geographic, paleoecologic, and stratigraphic distribution is the same as for *B. arvadensis*.

CYPRIDEINAE Martin, 1940
Bisulcocypridea Sohn, 1969

Remarks.—Sohn (1969) erected this as a subgenus to encompass bisulcate forms of *Cypridea* Bosquet, 1852. We regard *Bisulcocypridea* as a valid genus on the basis of its sulcation. This genus is potentially a transitional form between the Mesozoic–early Tertiary *Cypridea* and the late Tertiary–Holocene *Ilyocypris* (see Horne and Colin, 2005).

Bisulcocypridea arvadensis (Swain, 1949)

Figure 11*A–C*

Ilyocypris arvadensis Swain, 1949, pl. 32, figs. 20–21, pl. 33, figs. 1–9, p. 178.

Ilyocypris arvadensis tuberculata n. var. Swain, 1949, pl. 33, figs. 10–12, p. 179.

Remarks.—Swain (1949) provided a detailed description of this ostracode. It is easily identified by its two sulci (observed in the median region directly below the dorsum). We re-assign this species to *Bisulcocypridea arvadensis* because the sulci, carapace outline, and adductor muscle scars satisfy the criteria (Sohn, 1969) diagnostic for the genus. Tubercles are common on some specimens, and Swain (1949) regarded these as a new subspecies of *Ilyocypris arvadensis*. The nodeing, however, probably is an ecophenotypic response to changing water chemistry during carapace development (Carbonel et al., 1988). *Cypridea skeeteri* Peck, 1951 can be distinguished from *B. arvadensis* on the basis of a well-developed beak.

Occurrence.—*Bisulcocypridea arvadensis* and

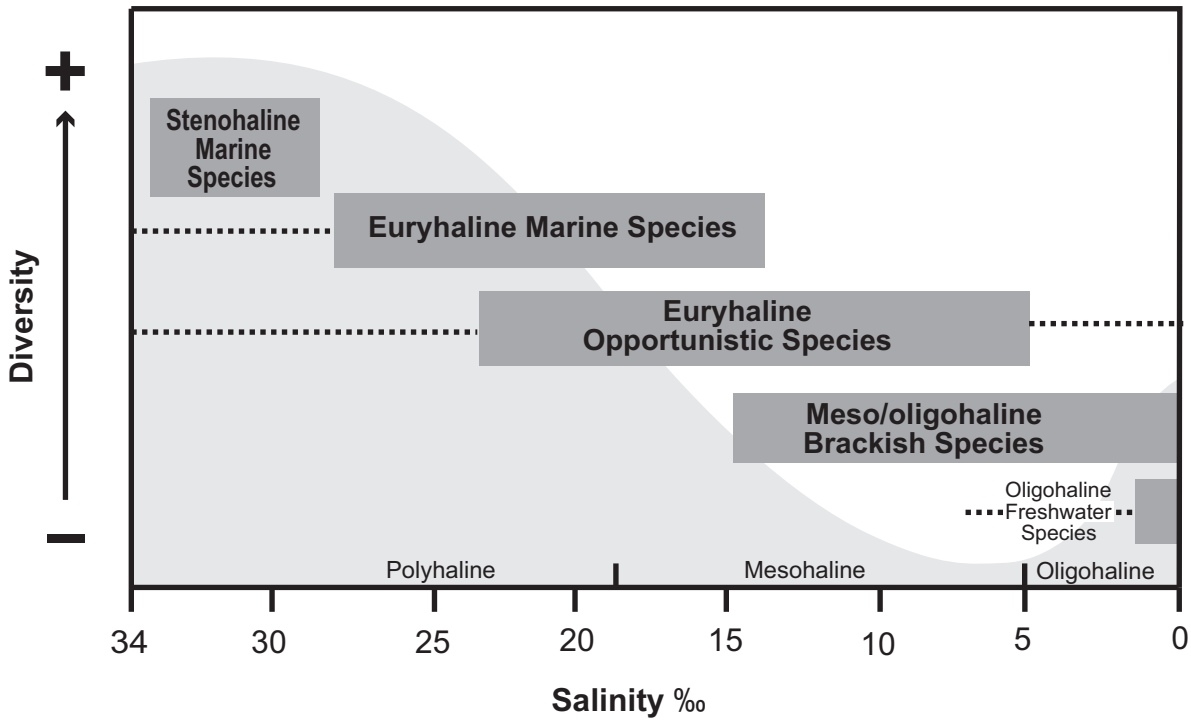

Figure 12. Ecological classification for organisms found in brackish-water environments. Boxes indicate optimal ranges (after Pemberton and Wightman, 1992). Grey background represents generalized species diversity across marine to freshwater transition (after Pemberton et al., 2001).

Candona occur in the Van Daele shell bed with *Pachydon mactriformis* (Fig. 4; Appendix 1, section LMR-B-100A, Unit 3). This ostracode assemblage comprises both adult and juvenile specimens, and the carapaces typically are disarticulated.

Paleoenvironmental significance.—Swain (1949) illustrated *Bisulcocypridea arvadensis* from the Tongue River Member of Montana. Brouwers and DeDeckker (1993) illustrated a similar species from nonmarine Danian strata in Alaska. The Cyprideinae are exclusively nonmarine, and the occurrence of *B. arvadensis* with specimens of *Candona* and charophytes indicates a low-salinity, nonmarine environment.

FOSSIL ASSOCIATIONS

Introduction

Eight trace-fossil ichnogenera with marine affinities occur in the Tongue River Member in eastern Montana and western North Dakota. Table 1 records their occurrences, relative abundances, and the names of the representative beds. The most important ichnofossil-bearing units include the *Monocraterion* bed, the *Ophiomorpha* bed, and the High Diversity (Hi. D.) burrow bed (Figs. 3 and 4). We designate the stratigraphically lowest, marine-influenced, burrowed units in the Tongue River Member as a "basal burrowed bed" (bbb).

All eight ichnogenera in the Tongue River Member have been documented in Cretaceous to Holocene marine deposits (Curran and Frey, 1977; Belt et al., 1983; Curran, 1985; Wightman et al., 1987; Pemberton et al., 2001). The most ubiquitous trace fossils include *Skolithos linearis* and *Teichichnus*. The other trace fossils, *Arenicolites*, *Diplocraterion*, *Monocraterion*, and *Thalassinoides*, are less widespread, and *Ophiomorpha* and *Rhizocorallium* are confined to only two of our study sites (Table 1). We recognize three estuarine assemblages as based on the occurrence and diversity of trace fossils. We also recognize an ostracode- and bivalve-dominated nonmarine assemblage. Paleosalinities of the burrowed beds and body fossils are inferred using a classification scheme (Fig. 12) modified from Pemberton and Wightman (1992).

Distal Estuarine Assemblage

Ophiomorpha is restricted to the Little Missouri River area (Fig. 1). Associated ichnogenera include *Diplocraterion*, *Monocraterion*, *Skolithos linearis*, *Teichichnus*, and *Thalassinoides*. We interpret this relatively highly diverse, *Ophiomorpha*-dominated assemblage as a steno- to polyhaline, distal estuarine deposit (Pemberton et al., 2001; Fig. 12).

Central Estuarine Assemblage

We interpret the moderately diverse burrowed beds that contain a combination of *S. linearis*, *Teichichnus, Diplocraterion, Thalassinoides,* and *Monocraterion* as a rich, brackish water assemblage. Ichnofossil associations dominated by *Teichichnus* are thought to represent central estuary deposits in Lower Cretaceous deposits in Alberta (Pemberton et al., 2001). Given the relative ichnogeneric richness and the presence of *Teichichnus* in beds of the Tongue River Member, we interpret this association as a mesohaline, central estuarine deposit (Fig. 12).

Proximal Estuarine Assemblage

Low-diversity beds containing *Skolithos linearis* and rare *Teichichnus* are ubiquitous throughout the stratigraphic interval, and we regard this assemblage as an indicator for oligohaline, proximal estuarine deposits (Fig. 12). Pemberton et al. (2001) regarded *S. linearis* as an indicator for Lower Cretaceous estuarine point-bar deposits in Alberta. The presence of bidirectional current ripples in our burrowed units supports a similar interpretation for *S. linearis* within the Tongue River Member.

Nonmarine Association

The poorly lithified muds of the Tongue River Member contain abundant, freshwater body fossils that include charophytes, viviparid gastropods, the bivalves *Plesielliptio* and *Pachydon mactriformis,* sphaerid bivalves, and nonmarine cypridacean ostracodes. Beds with nonmarine fossils in the gray mud facies intercalate with the sandy burrowed beds. The ostracodes *Cypridopsis*, *Candona*, and *Bisuclocypridea* are exclusively nonmarine, and the exclusion of brackish cytherid ostracodes indicates that the muddy facies were deposited in fresh water isolated from marine influence. The co-occurrence of the corbulid bivalve *Pachydon mactriformis* may represent a relict that was introduced by a far-reaching, marine flooding event (active transport during storm surges). Alternatively, that species may simply represent isolated freshwater conditions. Open marine conditions probably were never realized during deposition of the Tongue River Member, and the absence of marginal-marine foraminifera and/or ostracodes supports this idea. The sparse marine diatoms observed at select localities do, nevertheless, provide testament for marine influence.

DISCUSSION

Paleoenvironmental Synthesis

The paleontological evidence suggests that the typical nonmarine deposition of the Tongue River Member was interrupted by marine incursions from the Cannonball Sea that lay to the east. Beds with marine trace fossils represent brief transgressions of the shoreline into an otherwise nonmarine depositional setting.

The intimate association of marine and freshwater body fossils found within the marine burrowed beds support rapid and intermittent incursions of the Cannonball Sea. Association of nonmarine bivalves (*Pachydon* and *Plesielliptio*) and freshwater ostracodes (*Candona* and *Bisulcocypridea*) suggests deposition in fresh water that periodically covered the low-gradient coastal plain. In certain beds, freshwater deposition occurred before (and in other beds after) the marine episodes. Those that followed a marine incursion are consistently high-energy, cross-bedded sandstone that resulted from river-flooding events (Fig. 8*B*, and Hi. D. bed, Fig. 3). Thick, laterally extensive peat accumulated when rates of subsidence and peat accumulation were in equilibrium (Bohacs and Suter, 1997; Tibert et al., 2003).

Regional Implications

Strata in the Pine Hills area (Belt et al., 2004, fig. 6) show five burrowed beds that are spaced irregularly within 85 m of section in lower parts of the Tongue River Member. These specific beds have not been identified in the Signal Butte or Terry Badlands areas. Strata equivalent to these burrow beds in the Little Missouri River area would lie below the base of the Tongue River Member, within the upper Ludlow Member above the Oyster coal bed (Fig. 2; Belt et al., 2004, fig. 11).

These five burrowed beds, as well as the Hi. D. burrow bed, the *Monocraterion*, the *Arencolites,* and the *Rhizocorallium* burrow beds (Table 1) all fall within

the "Dominy" interval of the Tongue River Member west of the Cedar Creek anticline (CCA). Strata of the lower Tongue River Member east of the CCA on the Little Missouri River contain a basal burrow bed and the *Ophiomorpha* bed within the lower 15 m of the section (Table 1). These lower strata belong to the "Knobloch" interval that unconformably overlies the "Dominy" interval west of the CCA but directly overlies the Ludlow Member east of the CCA (Belt et al., 2004).

If this *Ophiomorpha* bed of the Tongue River Member were to be correlated westward into the Terry Badlands, Pine Hills, or Signal Butte areas, then strata younger than any studied by us there would have to be examined. At this time we are unable to assess the western extent of the *Ophiomorpha* bed (Table 1, Fig. 4) into eastern Montana. We are also unable to assess the correlation of the *Monocraterion*, *Arenicolites*, or *Rhizocorallium* beds eastward within the upper Ludlow Member in southwestern North Dakota. Occurrences of *Ophiomorpha* in the marine Three V Tongue above the Oyster coal of the Ludlow Member (van Alstine, 1974) are tantalizing, but inconclusive in terms of significance.

CONCLUSIONS

The Tongue River Member of the Fort Union Formation contains marine-influenced trace fossils in sandy burrowed beds that lie within specific study areas between Signal Butte on the west and the Little Missouri River district on the east (Fig. 1). Fine-grained sandstone units yield eight marine ichnogenera. The marine diatom *Coscinodiscus* occurs in basal sandstone units at two localities, one in eastern Montana and one in southwestern North Dakota. We recognize the following environmentally controlled fossil assemblages: (1) distal estuary, dominated by *Ophiomorpha*; (2) central estuary, with a relatively diverse ichnofauna (*Skolithos linearis, Teichichnus*, *Diplocraterion*, *Monocraterion*, and *Thallassinoides*); (3) proximal estuary, with a low-diversity association dominated by *Skolithos linearis*; and (4) coastal floodplain, dominated by nonmarine ostracodes (*Bisulcocypridea arvadensis*, *Candona*, and *Cypridopsis*) and freshwater bivalves (*Pachydon mactriformis* and *Plesielliptio*). The Tongue River Member was deposited on a low-gradient, coastal plain west of the margin of the Cannonball Sea.

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Paleontologists and Mineralogists Special Publication No. 40, p. 189–220.

CORRECTION: Two pollen biozone designations are missing from Section B-56 on figure 9, Belt et al., 2004, p. 124. The top coal of that section contains fossil pollen characteristic of palynozone P-5, and the next older coal has pollen characteristic of palynozone P-4.

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Appendix 1. Stratigraphic sections cited in text. Measured sections are listed numerically and with their locations.

*(1) Little Missouri River, North Dakota (*LMR*, Fig. 1).*

Note figures 4 and 5 by Belt et al. (1984), in which log and map positions of some of these sections are shown. LMR-B sections were measured by E. S. Belt (unpublished field notes, 1981–2002).

List of measured sections:

LMR-B-103: NW 1/4, Sec. 3, T. 136 N., R. 104 W.

LMR-B-102: SW 1/4, Sec. 36, T. 137 N., R. 104 W.

LMR-B-100: base at LONG 103° 42′ 42.99″ W, LAT 46° 38′ 9.43″ N.

LMR-B-56: north-central edge, Sec. 8, T. 136 N., R. 102 W.

LMR-B-12: base at river, south-central Sec. 31, T. 137 N., R. 103 W.

LMR-B-65: south-central part Sec. 31, T. 137 N., R. 103 W.

LMR-B-67: SE 1/4, Sec. 36, T. 137 N., R. 104 W., and SW 1/4, Sec. 31, T. 137 N., R. 103 W.

LMR-B-14: NE 1/4, Sec. 6, T. 136 N., R. 103 W.

*(2) Localities from badlands north of Terry, Montana (*TB*, Fig. 1).*

Previous mapping in this area was by Heffern (1981) and Vuke (1998a, 1998b). Six sections were measured by E. S. Belt, who was assisted by E. L. Heffern in 1982, by J. A. Diemer in 1997, and by N. E. Tibert in 1999. All measured sections are on Terry 7.5′ quadrangle.

List of measured sections:

Terry II: base below road level, SW 1/4, SE 1/4, Sec. 34, T. 13 N., R. 50 E. Extends to clinker at top of butte.

Mushroom Café section: LONG 105° 21.743′ W, LAT 46° 50.124′ N.

Paleovalley section: base at 45 m below road level, 643 m due west of top of Terry II section.

*(3) Signal Butte sections, Miles City, Montana (*SB*, Fig. 1).*

Measured by Belt, who was assisted in 1982 by E. L. Heffern, in 1997 by J. A. Diemer, and in 1999 by N. E. Tibert. Clinker underlies radio towers serving Miles City.

SB-II: base at upper Lebo D-coal, top at Tongue River clinker, eastern approach to Signal Butte, base lies mid-boundary between Sec. 6 (west) and 5 (east).

*(4) Pine Hills study area, near Locate, Montana (*PH*, Fig. 1).*

These sections (in SE quadrant of Buck Mountain 7.5′ quadrangle) were used in previous research by Belt et al. (1992).

List of measured sections:

PH-B-33: SW 1/4, Sec. 12, T. 7 N., R. 50 E.

PH-B-31: SW 1/4, Sec. 1, T. 7 N., R. 50 E.